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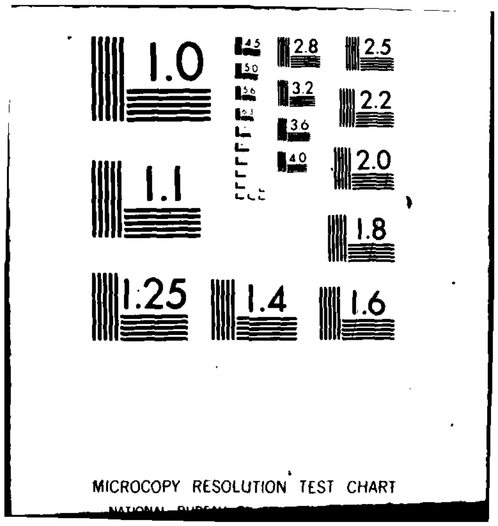
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EVALUATION OF BREATHING MIXTURES TO BE USED DURING DECOMPRESSION FOR MIXED GAS SURFACE SUPPLIED DIVES

by

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INTRODUCTION

In a dynamic field, such as decompression computation, the "state of the art" is constantly changing. ıhe best methods achievable by man in devising decompression schedules 50 years ago, are obsolete by todays standards. The present surface supplied mixed gas tables were, at the time they were developed, a major advance in deep diving procedures and were probably as great an achievment as could be reasonably expected considering the state of the art at that time. However, the rapid increase in man's knowledge of decompression requirements have increased the state of the art of decompression computation to the point at which the methods utilized for computations 50 years ago must be regarded as primitive by comtemporary standards. The utilization of modern methods of table analysis together with a number of examples of problems in the field have indicated that the present schedules are inadequate to provide for more than the most limited areas of application in terms of depth and exposure time. Further, experimental tests using modern methods of decompression computations have illustrated that the present state of the art can permit significantly large extensions of the presently applicable exposure time currently possible with the present tables.

It would be extremely conceited and shortsighted to assume that today's knowledge will reamin unimproved over the next 50 year period. Indeed some interesting variations in decompression response between groups of individuals exposed to pressure and variations in individual response to decompression over various periods of time indicate the need for several new avenues of investigation to provide more complete knowledge of the decompression requirements for man. Realistically, all one can hope to achieve is to accomplish the best possible output which the present state-of-the-art will permit. If, as seems indicated by problems encountered with the present Navy Surface Supplied Mixed Gas Tables, that new schedules should be developed, it would seem desirable that they provide the most advantageous forms of diving procedures that contemporary methods can devise. Hopefully, this could result in schedules which, 50 years hence, would reflect as much merit for the time in which they are developed as the present Mixed Gas Schedules reflect merit when viewed in consideration of the time in which they were constructed.

One important tool in table computation is shifting inert gasses during decompression. Proper application of this technique may result in the saving of large percentages of decompression time. In the case of a dive involving the use of helium-oxygen on the bottom, the standard procedure involves switching the breathing mixture to nitrogen-oxygen during decompression. In this case, added advantages of improved thermal comfort to the diver and generally better communications from the diver to surface are provided by this switching technique. This technique has been extensively used with very good results in foreign naval and domestic, as well as foreign, commercial diving operations over the past decade and proper application of this technique would provide significant reductions in decompression requirements for and future recomputation of the U. S. Navy Surface Supplied Mixed Gas Tables.

It is the purpose of this study to make a mathematical evaluation of various possible nitrogen-oxygen mixtures and optimum depth at which they might be applied during the decompression following a helium-oxygen exposure within the anticipated depth-time requirements of the U. S. Navy.

BACKGROUND

The initial use of helium-oxygen for diving by the U. S. Navy utilized schedules in which the helium-oxygen was used as the breathing mixtures during decompression until the final water stages where oxygen was supplied to the diver, Momsen(1). Although provisions were made for an alternate form of decompression in which air could be breathed during decompression (U.S.Navy Diving Manual (2)), this procedure was only provided for emergency use where the planned helium-oxygen breathing mixtures could not be supplied to the diver.

It was the Royal Swedish Navy who first utilized a special breathing mixture for use during decompression as a standard (and indeed necessary) procedure in their experimental use of hydrogen-oxygen diving (Bjurstedt and Severin (3). In this case a breathing mixture containing 4% oxygen with the balance of hydrogen or hydrogen and nitrogen was used during the time the diver was below 5 atmospheres absolute.. The low oxygen percentage was necessary to provide a mixture which, with hydrogen was non-explosive and non-flamable. Since this mixture would be hypoxic at depths below 5 atmospheres absolute the diver was switched to air (after a brief period breathing 94%N2-4%02) and continued his compression with this breathing mixture.

The technique of shifting to air during decompression following exposures at higher pressures with hydrogen-oxygen was later used by Edel (4) using inert gas shifting techniques which had previously been utilized for use in commercial decompression tables following exposures with helium-oxygen mixtures. Extensive use of inert gas shifting was used by Keller(5) in experimental dives to depths as deep as 1000 FSW. Today the vast majority of U. S. Commercial diving companies utilize some form in inert gas shifting during decompression following helium-oxygen exposures at depth and many companies have been successfully using such methods for over a decade.

In the utilization of the inert gas shift during decompression, the principal objective is to reduce decompression time by taking advantage of the differences in the rate of uptake and elimination between inerts. The principal application of this technique involves shifting to air, or a nitrogen-oxygen mixture, during decompression following an exposure at greater pressure with helium-oxygen or, less often, helium-nitrogen-oxygen mixtures. The relative rate of inert gas exchange between helium and nitrogen, based upon a combination of mathematical evaluation of the physical constants and evaluation of the response to comparative decompression profile in manned experiments, according to various contemporary investigators, appears to be between 2.6:1 (Buhlmann (6) and 2:1 (Edel (7)). In either case it is assumed that a switch to a nitrogen-oxygen mixture during decompression will allow the helium to be eliminated at a comparatively rapid rate while the nitrogen is being taken up by the tissues at a much slower rate with a resulting increased rate of total gas elimination described by summation of the He+N2 gas tissue tensions in a given half-time compartment. The more rapid rate of total inert gas elimination will then permit a more rapid rate of pressure reduction and allow the diver to reach surface pressure with a shorter period of decompression as compared to a diver who continued decompression breathing helium-oxygen.

BASIC CONSIDERATIONS FOR SHIFTING INERT GAS MIXTURES DURING DECOMPRESSION

For the sake of mathematical convenience (rather than an supposed suggestion of correctness) we will assume a helium/nitrogen ratio of 2:1 for subsequent examples in the application of inert gas shifting. Further we need to select a tissue half-time tissue constant. If we chose the widely accepted value of 5 minutes for the fastest tissue half-time compartment with nitrogen, the corresponding value for helium (if one assumed that the ratio were to be valid for the faster tissue half-time compartments) of 2.5 minutes. If we then apply these values to Workman's M-values for helium-oxygen (8) we see that we could leave a 20 ft. stop with 101 FSW in the fastest tissue half-time compartment and must reduce this value by 15 FSW before we could arrive at surface pressure. This would require a reduction of 86/101 or approximately 85% of the inert gas load in the fastest tissue compartment on arrival at 10 FSW. This would, however, imply an outward inert gas gradient of 100%. If the diver were breathing a mixture to 80%He-20%02 the inspired inert gas partial pressure would be 80% of the absolute depth (10+33 FSW (partial pressure at sea level)) or .8 X 43 = 34.4 FSW. Subtracting this value from the inert partial pressure of helium in the divers fastest tissue compartment upon arrival at 10 FSW gives 101 - 34.4 = 66.6 FSW. Since 15 FSW needs to be eliminated prior to ascending to surface,the value must be reduced to 51.6/66.6 or approximately 77.5% before ascending from the 10 FSW level. Breathing helium oxygen this would require slightly over 2 minutes (using the classical Haldanian formula for inert gas uptake and elimination). If we were to shift to a mixture of 80%N2-20%02 we would have the total outward gradient available for elimination and would reduce the He partial pressure in the tissues to this value in slightly over a minute. However, we would still be taking up nitrogen which must be added to the helium for summation of total inert gas in the tissue compartment and the addition of almost 2.5 FSW of nitrogen would prevent us from achieving the required reduction in tissue tension within this period of time. In fact, it would theoritically require (without consideration of other factors) at least 1.5 minutes to achieve this value (or a reduction of time of 25%) which is not very impressive. It would be even less impressive if the use of oxygen were considered. With oxygen the inspired total inert gas partial pressure would (in sufficient time) provide an outward gradient of close to 100% allowing for an ascent to surface pressure in one minute (under theoritically ideal conditions). Further, this is based upon the assumption that the He/N2 inert gas exchange ratio which has been determined for the slower tissue half-time compartments exists for the faster tissues compartments as well. This is not in fact suggested by the gas soluability and diffusion coefficients or computer analysis of experimental data by the Autodec system.

In the slower tissue half-time compartments, the amount of excess inert gas which may be tolerated by the tissues is vastly reduced. Workman's M-values provide for arriving at 10 FSW with a tissue tension of 63 FSW and 10 FSW must be elminated for arrival at surface pressure. Again assuming a breathing mixture of 80%He-20%O2 arrival at 10 FSW would produce a gradient of 63-34.4 FSW or 28.6 FSW and requires a reduction of 10 FSW prior to ascent to surface pressure to 18.6/28.6 = 65%. For a helium tissue half-time compartment, this would require 85 minutes. However, if a switch 80%N2-20%O2 is made, after 50 minutes the helium tissue tension is reduced to 47.2 FSW while a nitrogen uptake of 4.6 FSW occures for a total of 47.2 + 4.6 = 51.8, well below the required limit. This produces a savings of 40% or 35 minutes which would appear to be a substantial benefit.

The increase in percentage of time saved in the latter case is due to the relative difference in the gradients for helium elimination. In the initial case, the outward gradient for helium, when breathing HeO2 as compared with N2O2 is small as compared with the relative increase in the gradient possible with a shift to nitrogen-oxygen. The inward nitrogen gradient remains the same in all cases and hence does not play a role in relative gas elimination efficiency.

Hence, it would appear that in addition to savings in terms of actual time, the relative efficiency of gas elimination will increase as the time constants (with corresponding decreases in permissible safe excess gas tissue tensions) are increased. This would suggest that the technique of inert gas shifting should be directed towards the elimination of gas in slower tissue compartments where the actual time saved and relative efficiency of inert gas transfer, is the greatest.

In both cases, it was assumed that no change would take place in the inert/oxygen ratio. However, the maximum permissible percentage of oxygen, resulting in a limiting oxygen partial pressure for a given depth-time exposure, provides a lower partial pressure during decompression as the ambient pressure is lowered. During decompression, the oxygen percentage may be increased in the nitrogen-oxygen mixture to further lower the inward gradient of nitrogen and hence further increase the overall efficiency of inert gas elimination. The percentage must be selected with consideration of the amount of exposure time on this mixture and relative exposure times at lower pressure stages while the oxygen partial pressure is reduced but still above the permissible limits for an indefinite period of residence. Commercial practice indicates that shifts to a nitrogen-oxygen mixture with a partial pressure as high as 2ATA may be applied safely as a one time procedure, with a later shift to pure oxygen if desired, for the vast majority of schedules used in commercial practice. This value was applied for use in computer evaluation of the shifting procedures and establishes an upper limit for switching to the mixtures during decompression. Hence, a shift could be made to a mixture of 50%N2-50%02 at a maximum depth of 100 FSW and to a mixture of 60%N2-40%02 at a maximum depth of 130 FSW during decompression in the water. This would suggest the ability to shift to air at a maximum depth of 280 FSW. However, commercial practice has indicated that switching from helium-oxygen to nitrogen-oxygen mixtures at depths below 150 FSW can, under some conditions, result in vestibular decompression sickness and hence 150 FSW would appear to be a reasonable upper limit for such a shift were no special procedures are applied. This then is used as the upper limit for all shifts from He-02 in addition to any limits implied by the partial pressure of oxygen in the mixture.

The mechanics of shifting mixtures must also be considered. A certain amount of communication between the diver and the surface is necessary for the amount of mutual cooperation required to achieve the gas shift and insure that the gas shift has been made (as example by noting the change in the divers voice), and allow for the gas to be delivered to the diver and/or replace the previous mixture in the diver's suit. It is assumed that, without special procedures and training, this could not be normally accomplished in less than 5 minutes. Hence, in addition to other considerations, it is considered that no shift would take place unless the decompression stop at which the shift is planned would be of at least 5 minutes duration. This imposes no significant restrictions since the shorter decompression stops are controlled by the faster tissue compartments where the effectiveness of such a shift would be minimal.

The optimum decompression mixture may depend upon a number of factors. For example, a dive which results in a relatively shallow initial decompression stop (below 100 FSW) may result in optimum decompression with switch to a 50%N2-50%02 mixture as this would produce the minimum inward gradient for nitrogen. In a dive with a relatively deep initial stop the time required in decompression to 100 FSW may override the gains provided by the reduced inward gradient of this mixture as compared to switching to air at a deeper level. Likewise, the optimum depth at which the shift is made may depend on the profile in question. Shifting in too shallow may not result in the maximum possible elimination of helium while shifting into the nitrogen-oxygen mixture at too deep a depth in some profiles may result in a large buildup of nitrogen in the tissue compartments in the later stages of decompression which, considering the comparatively slow time constants for nitrogen, could result in decompression time requirements at the shallow depths which more than offset the advantages to be gained by the shifting technique. These conditions may be further modified by the use, or probition, of oxygen for the final stages of decompression in the water. In some profiles, the partial pressure of oxygen in the N2-02 mixture may result in prohibitively high COTD values or prohibit the use of pure oxygen at later stages. Like decompression requirements per se, each individual exposure may have its corresponding optimum solution for the oxygen percentage in nitrogen for the decompression mixture and the depth at which the shift should be made. A recommendation for a generalized or standardized solution involving the use of one specified N2-02 mixture to be applied at one specified depth for all profiles, requires an evaluation of the average merits of a specific solution over the depth-time profiles which may be of interest to the Navy. It is the purpose of the computer analysis to indicate the merits of various specific procedures which could be applied over practial range of application of mixed gas diving tables.

COMPUTER EVALUATION OF NITROGEN-OXYGEN MIXTURES AND SWITCHING DEPTH

The Autodec system was used to evaluate the switch from He-02 in the active mode (generating, as opposed to analyzing, tables) for the profiles in question. The subject index for all schedules was set to match the response for the test subjects used in the experimental program to determine safe tissue tensions during the surface interval in surface decompression schedules for helium-oxygen dives. This was done to permit computer evaluations to be matched with previous manned data on file.

Nine basic profiles were used to evaluate the switching procedures to cover anticipated maximum, minimum and intermediate depths with short moderate and long exposure times. The depths selected were: 150, 225 and 300 FSW. In all cases, a minimum exposure of 10 minutes was used, but the maximum time (and hence the intermediate time as well) was chosen on the basis of predicted maximum probable exposure times for the depth in question.

The base profile depths and time are shown in table I

TABLE I

DEPTH (FSW)	EXPOSURE TIMES (MIN.)		
150	10	120	240
225	10	60	120
300	10	30	60

In all cases, it was assumed that the dives would be made using 84%He-16%02. It should be noted that some schedules involve violations of the normal exposure oxygen partial pressure limits, however, it was considered more important for the purposes of comparison to utilize a single He-02 mixture for all conditions.

The surface decompression dives listed in Table I were evaluated under two major conditions:

A. Use of oxygen at the final water stop; and

B. Without use of oxygen at the final water stop.

Where oxygen was used it was assumed that the diver would surface from a final water stop of 50 FSW as indicated by the experimental profile in a previous study, Edel (9). Also, as indicated by the results of further experiments in a continuation of that program, when oxygen was not utilized during water decompression the computer provided a profile for surfacing the diver from a final water stop of 40 FSW.

For each condition the computer was instructed to provide decompression in four formats:

1. Decompression on the helium-oxygen mixture used at maximum depth.
2. Shifting to air during decompression.
3. Shifting to a mixture of 60%N2-40%02 and 4.
4. Shifting to 50%N2-50%02 during decompression.

In all cases intermittant oxygen - air breathing was programmed for use in the surface decompression chamber.

Although the principal objective was to make an evaluation of inert gas shifting procedures for surface supplied mixed gas dives in the surface decompression mode, an additional evaluation was also made for the bell mode with a capability for TUP assumed. In this case, it was considered that the implied sophistication of this diving mode and the extended requirements for operational usage would permit some increased complexity in utilization of inert gas shifting methods. In this case, it was assumed that when shifting techniques were applied, for the purpose of evaluation, and applied to nitrogen-oxygen mixtures, that a shift to an N2-02 mixture could be preceeded by one to air. In addition to the use of the above, the possibility of shifting from helium-oxygen to a multi-inert mixture followed by a shift to air, followed by a shift to a nitrogen-oxygen mixture was examined. In all cases, it was assumed that intermittant air-oxygen breathing would be initiated at the 60 FSW level.

RESULTS

Surface Decompression Dives

In the case of the 10 minute exposure to 150 the initial stop was too shallow (and the time at the stop of too short a duration) to result in any effect from gas shifting. In the cases of the 10 minute exposure to 225 and 300 FSW deeper stops were required but the time at these stops (controlled by the faster tissue compartments) was too short (usually 1 or 2 minutes) to adequately permit a gas shift to be made. In addition, these schedules involved such high helium partial pressure gradients that the effect of a shift to a nitrogen-oxygen mixture would not produce any significant change in the overall water, or total, decompression times. Indeed the gradients were sufficiently high as to eliminate any significant advantage between utilizing the helium-oxygen mixture during the entire water decompression phase and use of oxygen at the final water stop. The results are shown in Table 2.

TABLE 2

DEPTH (FSW)	TOB (min.)	02 AT FINAL STOP (decompression time)*		NO 02 AT FINAL STOP (decompression time)*	
		Water	Total	Water	Table
150	10	0:12	0:49	0:12	0:49
225	10	0:20	1:07	0:22	1:29
300	10	0:35	1:42	0:42	1:49

* Decompression times in hours : minutes.

In the remaining cases switches to N2-02 mixtures produced significant changes in the total decompression time as shown in Table 3 and the water decompresion time as shown in Table 4.

TABLE 3

TOTAL DECOMPRESSION TIME (HRS.:MIN.)
(Gas Mixtures Used With Decompression)

DEPTH (FSW)	TOB (min.)	HeO2	HeO2/O2	Air	Air/O2	60%N2	60%N2/O2	50%N2	50%N2/O2
150	120	8:00	6:04	5:29	5:08	5:08	4:59	4:44	4:38*
150	240	14:45	11:44	9:45	8:54	8:55	8:14	8:25	7:54*
225	60	8:03	6:27	5:33	5:27	5:23	5:02	4:33	4:17*
225	120	16:22	13:21	10:46	9:31	9:07	8:36*	9:37	9:06
300	30	6:42	5:36	4:47	4:41	4:31	4:07	4:07	3:08*
300	60	13:33	11:37	9:43	8:27	8:13	7:57*	8:33	8:22

* Optimum mixture

TABLE 4

WATER DECOMPRESSION TIME (HRS.:MIN)
(gas mixtures used with decompression)

DEPTH (FSW)	TOB (min.)	HeO2	HeO2/O2	Air	Air/O2	60%N2	60%N2/O2	50%N2	50%N2/O2
150	120	4:11	2:10	2:11	1:10*	1:51	1:10*	1:41	1:10*
150	240	9:57	6:06	4:07	2:46	3:32	3:26	3:07	2:16*
225	60	4:50	2:49	2:30	1:29	1:55	1:14*	2:05	1:33
225	120	11:34	7:43	5:04	3:23	3:54	2:58*	4:29	3:28
300	30	3:49	2:28	2:09	1:33	1:44	1:23*	1:44	1:23*
300	60	9:05	6:34	4:50	3:29	4:00	3:09*	4:15	3:34

*Optimum mixture

As may be seen from Table 3, decompression on helium-oxygen produced the longest decompression times throughout the entire contemplated range of exposures. While shifting to air produced a significant overall advantage, this method was noticably less advantageous than utilizing nitrogen-oxygen mixtures with higher oxygen percentages. In general there was also a significant advantage to the use of oxygen at the final decompression stop as opposed to completing the total water decompression phase without oxygen. As can be seen from Table 4, these advantages applied to the water decompression time as well as the total decompression requirement. Shifting to a mixture of 50%N2-50%02 with a final period of oxygen breathing at the final stop resulted in the shortest total decompression time from the shallow depths and the inertmiatate exposure times at the moderate and deep levels. It was only for the longer exposure times at the deep and moderate depths wherein an advantage was gained in using the 60%N2-40%02 mixture in preference to the 50%N2-50%02 mixture.

While the comparative results of total decompression time requirements are of academic interest, it is Table 4 which is of greater concern to one activity engaged in practical diving operations with surface decompression dives. It is possible to utilize relatively long decompression times in a deck chamber where the diver can be directly observed and is comfortable, warm, can be fed, and can be attended to rapidly in an emergency. This more secure environment also results in reduced stress for both the diver and those who are responsible for his health and well being. When the diver is in the water, the reverse is true and the numerous factors require restricitions of the time spent by the diver during the period he is directly exposed to the water.

As shown in Table 4, the use of 50%N2-50%02 mixture is still advantageous for long exposure at 150 FSW and equally beneficial (as the 60%N2-40%02 mixture) for moderate exposures at the shallow and deep depths. However, except for the sole case of a long exposure at the shallow depths, the 60%N2-40%02 mixture was superior to, or as effective as, any other mixture with respect to reduction of in-water decompression time.

The depth at which the switch was made from helium-oxygen to nitrogen was the maximum permissible in all cases shown in Tables 3 and 4. In all cases, any reduction of the "switch depth" resulted in an increase in decompression time. An example of the change of decompression time with depth at which a switch is made to a 60%N2-40%02 mixture (with pure oxygen for the final 10 minutes at the final water stop) for a dive to 225 FSW for 60 min. is shown in Table 5.

TABLE 5

SWITCH DEPTH	WATER DECOMPRESSION TIME	TOTAL DECOMPRESSION TIME
No shift made	2:49	6:27
60	2:39	6:17
70	2:09	6:07
80	1:59	5:57
90	1:59	5:47
100	1:34	5:32
110	1:29	5:17
120	1:19	5:07
130	1:14	5:02

Bell Dives with TUP

Table 6 shows the decompression shift sequences evaluated by the program. In all cases, it was assumed that the breathing mixture on bottom would be 90%He-10%02 and that this mixture would be used alone or until a shift was made during decompression. In all cases, the computer was programmed to start air-oxygen breathing at 60 FSW. However, in some of the longer dives the total prior oxygen dosage was beyond the computers limit criteria for such a procedure. In such cases, the computer initiated a shift to air at 60 FSW and started the air-oxygen breathing at a lower level (50 FSW in most cases). When a MI is indicated, a multi-inert mixture (20%02-40%N2-40%He) was utilized prior to shifting to air.

TABLE 6

CONDITION	SHIFTING SEQUENCE
A	He-02 only
B	He-02 to air
C	He-02 to air to 60%N2-40%02
D	He-02 to air to 50%N2-50%02
E	He-02 to MI to air to 60%N2-40%02
F	He-02 to MI to air to 50%N2-50%02

Table 7 shows the computer determined decompression times for the above conditions.

TABLE 7

DEPTH	TOB	SWITCHING PROCEDURES					
(FSW)	(min)	A	B	C	D	E	F
150	30	0:37	(not applicable for shifting to other mixes)				
150	180	8:26	7:16	7:11	7:06*	NA	NA
150	360	18:11	13:37	12:42	12:02*	NA	NA
300	30	6:33	4:33	4:13*	4:13*	NA	NA
300	60	15:36	13:17	9:22	9:22	8:36	8:32*
300	120	28:58	31:23	26:04	26:33	22:16*	22:26
450	30	14:47	11:52	10:47	11:07	9:41	9:17*
450	45	24:00	20:50	20:50	21:20	17:10*	17:10*
450	60	28:50	37:25	29:25	33:35	26:20	26:10*

* Optimum prodedure

DISCUSSION

For surface supplied mixed gas surface decompression dives, it would appear that the short exposure dives would not be noticably improved by the utilization of switching to a nitrogen-oxygen mixture during decompression due to the shallow initial decompression stops and/or the relatively rapid rate of decompression with faster tissue compartments controlling the decompression. For other dives in general the optimum mixture for minimum total decompression time would be a 50%N2-50%02 mixture. However, the greatest restriction with respect to such diving procedures is the water decompression time with its attendant problems of exposure hazards, discomfort, inability to provide maximum possible aid and assistance in emergencies, physiological stress, and inability for the diver to eat, drink and eliminate body wastes. Since the maximum possible TOB is primarily restricted by the duration of the exposure in the water, reduction of the water decompression phase of the dive is considered to have a higher priority over total decompression time per se. In this respect a 60%N2-40%02 appears to provide the maximum advantage possible with a single decompression mixture. This is apparently due to the fact that it can be applied at a deeper depth than a 50%N2-50%02 mixture and hence provides a favorable exchange rate over a longer period of time than a N2-02 mixture with a higher oxygen percentage. In general, it would appear that a shift to this mixture should be made at the deepest depth consistant with the oxygen percentage and practical problems of implementing a shift in breathing mixture to the diver. In addition, the figures indicate that a significant advantage in reduction of decompression time results from the use of oxygen during the last portion of the final water stop. In general, 10 minutes of oxygen breathing just prior to starting ascent for the surface interval would be sufficient to eliminate sufficient inert gas from the faster tissue compartments to permit the ascent to the surface at the earliest possible time consistant with diver safety. In general, it would appear that the optimum depth for a final water decompression stop would be 50 FSW. The evaluation indicates that this would permit dives of two hour duration within the 150-220 FSW depth range and dive durations providing equivalent gas loadings below that depth. A slight reduction of the oxygen percentage in the helium mixture or an auxiliary He-02 mixture with reduced oxygen percentage would permit dives as long as 60 minutes at 300 FSW.

The use of a bell with TUP capabilities could extend the usefulness of nonsaturation diving techniques. However, for dives significantly beyond the surface decompression mode limits , the prolonged decompression times required below 150 FSW (where the earliest shift could be made to air with safety) are already restricting the usefulness of shift to a nitrogen-oxygen mixture. This may be overcome to some extent by introducing a multi-inert mixture for the more obligating exposures at substantially deeper depths. This could permit exposures for as long as 90 minutes at 300 FSW or 45 minutes at 450 FSW within reasonable bell decompression time limitations. Because of the increased relative complexity of such dives, it would be preferable to individual assess the shifting requirements of each depth-time combination for optimum results. In general, it would appear that a procedure involving a shift from helium-oxygen to a multiple inert mixture, then to air, followed by a shift to a 50%N2-50%02 mixture with intermittant air-oxygen breathing through the 60 to 10 FSW stages would produce the best results. In addition, it would appear that, in general, the shifts should be made at the deepest depths possible for the specified mixtures consistant with other factors and restrictions.

In addition to other factors (such as the provision of sleeping periods during decompression), the computer printouts from the 450 FSW dives for 60 minutes indicate a point at which the shifting technique is loosing effectiveness. The reversal of the ratio between condition A (where helium-oxygen alone is used during decompression to the 60 FSW level) and shifting to air and/or N2-02 mixtures (with exception of cases in which multiple-inert mixtures were used) indicates that the nitrogen buildup in the slowest tissue compartments is starting to limit decompression at a depth which overbalances the gains at the deeper levels made possible by the shifting technique. Hence, dives significantly extended beyond this depth-time combination would be very restrictive in terms of applications of switching to N2-02 mixtures during decompression.

CONCLUSIONS AND RECOMMENDATIONS

1. That future recomputations of surface supplied mixed gas surface decompression schedules utilize a shift to a 60%N2-40%02 mixture during decompression in schedules wherein the depth of the initial stop is below the depth of the final water stop, and sufficient time is available (5 minutes or greater) at that level to complete the shift from helium-oxygen.

2. That the shift be initiated at the maximum possible depth with respect to the above recommendation but not to exceed 130 FSW or involve such periods of time at this and subsequent decompression stages as to involve a hazard with respect to CNS oxygen toxicity.

3. That at least 10 minutes of oxygen breathing be used at the end of the final water decompression stage.

4. For optimum results a final water decompression stage of 50 FSW is recommended.

5. For exposure involving the use of diving bells with TUB capability the shifting sequence during decompression from He-02 to He-N2-02 to air to 50%N2-50%02 with intermittant air-oxygen from 60 FSW to surface is recommended.

REFERENCES

1. Momsen, C. B. & Wheland, K. R. (1939). Report on Use of Helium Mixtures for Diving. (Revised 1942) U. S. Navy Experimental Diving Unit, Washington, D. C.

2. U. S. Navy Diving Manual (NAVSHIPS 0094-001-9010) Washington, D. C. U. S. Government Printing Office, 1970.

3. Bjurstedt, H. and Severin, G. The Prevention of Decompression Sickness and Nitrogen Narcosis by the Use of Hydrogen as a Substitute for Nitrogen. in: Mil. Surg, 103: 107-116, 1948.

4. Edel, P. O., Preliminary Studies of Hydrogen-Oxygen Breathing Mixtures for Deep Sea Diving in: Oceanology International 72 Conference Papers, 485-489, Society for Underwater Technology, 1 Birdcage Walk, London, S.W. 1, (1972).

5. Keller, H. Use of Multiple Inert Mixtures in Deep Diving in: Proceedings of the Third Underwater Physiology Symposium. Ed. Lambertsen, D. J., pp. 267 - 274. Baltimore: Williams and Wilkins. (1967)

6. Buhlmann, A. A. The Use of Multiple Inert Gas Mixtures in Decompression in: Bennett, P. B. and D. H. Elliott, eds. The Physiology and Medicine of Diving and Compressed Air Work, pp. 357-385. Baltimore, Williams & Wilkins, (1969).

7. Edel, P. O. Report on Project Hydrox II, Harvey, Louisiana, Michel LeCler, Inc., final report on contract N00014-73-0233, 76 p. August, 1974.

8. Workman, R. D. (1965). Calculation of Decompression Schedules for Nitrogen-oxygen and Helium-oxygen Dives. Research report 6-65. U. S. Navy Experimental Diving Unit, Washington, D. C.

9. Edel, P. O., Determination of Safe Tissue Tension Values During the "Surface Interval in Surface Decompression Schedules for Helium-Oxygen Dives", in Proceedings of the Seventh Symposium on Underwater Physiology.

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FIGURE #1

AUTODEC N_2 CALIBRATION ENVELOPE